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How Electrical Storage Heaters Can Reduce Wind Curtailment by Satisfying System Reserve Requirements

William D. Kerr , *David* M. Laverty, and *Robert* J. Best

School of Electronics, Electrical Engineering and Computer Science, Energy, Power and Intelligent Control (EPIC), Queen's University Belfast, Belfast, Northern Ireland

Abstract. This paper proposes how using electric storage heaters could provide a portion of the system reserve requirements which would otherwise have to be satisfied by conventional generation. With the upgrade and install of new advanced electrical storage heaters there is the potential to provide large system reserve capabilities when combined with a high-speed communications network. Together with these new more efficient heaters, not only will domestic emissions be reduced, the overall electrical grid CO2 intensity should experience an improvement due to the incorporation of the demand side management (DSM) aspect. The All-Ireland system has been used in this paper as an example of an electrical network which is undergoing a significant transition to high penetrations of renewables, while having a considerable population of potentially upgradeable electric heating sources for DSM control.

1 Introduction

As the world's electrical generation changes to incorporate large amounts of renewable energy, many new operating problems have arisen on electricity networks. The island of Ireland is such an example. Due to strict EU emissions polices both the Republic of Ireland (ROI) and Northern Ireland (NI) have set targets of 40% RES-E (Renewable Energy Sources – Electricity) by 2020 [1], [2]. In order to achieve this ambitious RES-E figure, 37% will be provide by wind generation, with the other 3% coming from various other sources [3]. The issue with this is that wind is the largest contributor to system non-synchronous penetration (SNSP), which is the percentage of total generation permitted from non-synchronous sources. This is exacerbated by the fact that the island has only two DC interconnectors of low capacity with Great Britain (GB). Consequently, the island's power system frequently operates with an SNSP of up to 65%. At this point the SNSP is curtailed due to stability concerns [4]. However, the SNSP is only part of reason wind has to be curtailed, accounting for 15.6% of the total dispatch-down [5]. Dispatch-down refers to the amount of wind energy which is available but cannot be produced due to a number of reasons, detailed in part II. Based on this, a major transition on the whole system (generation and demand) is necessary, as without this the 2020 RES-E targets would be economically impossible to reach due to the amount of wind dispatch-down. This situation will become internationally relevant as larger countries and land masses, such as GB, start to increase their renewable energy penetration to the same sort of levels. Some countries are currently running at much higher SNSP levels, for example Denmark. At the start of July 2015, Denmark was producing up to 140% of its demand from wind generation alone [6], with 42% of 2015 total electrical power generation coming from wind [7]. Denmark can currently cope with this very high wind penetration as it is heavily interconnected with Germany, Norway and Sweden. The problem with relying on interconnectors for overflow power is that wind is likely to become the major renewable source for many countries due to the maturity of the technology. This means there is going to become a point when exporting is no longer a viable option in regard to increasing SNSP, due to the receiving countries experiencing their own problems with wind and solar PV penetration. This is already under consideration from SONI, the NI transmission system operator (TSO), which limits the export capacity on the Moyle DC interconnector when modelling future constraint requirements, due to emerging network limitations in GB [8]. In light of these conceivable problems on the power networks, storage and demand side management (DSM) are considered as a solution.

In Ireland, residential space and water heating accounts for approximately 19% of the total energy consumption of the country [9], [10]. Of this heating, there is a modest amount of installed domestic electric heating on the island, with the latest census data showing Ireland having 13.5% electric central heating and Northern Ireland having 5% electric central heating [11], [12]. A report by consultancy company DNV KEMA Energy & Sustainability, which was commissioned by Glen Dimplex and SSE Plc, also claimed that Ireland has a potential electrical heating replacement of around

1 GW for distributed controllable capacity on the grid [13]. Along with updating current electric heating methods we must consider the potential replacement of typical heating methods with electric heating.

2 Reasons for dispatch-down

In previous years dispatch-down was calculated at the end of the year for a subset of windfarms and extrapolated for the rest, to give constraints and curtailment. From 2016 EirGrid now records real time wind dispatch-down into four main categories [5]:

1) *Transmission Constraints:*

This occurs due to resolving local network issues and is mainly due to line capacities.

2) *Transmission Testing:*

Occurs when wind farm testing is carried out by the TSO, e.g. for commissioning and monitoring.

3) *Curtailments:*

a) *High Frequency/Minimum Generation:* This occurs when attempting to alleviate an emergency high frequency event or when reserve requirements mean a minimum level of conventional generation necessary, priority dispatch or to provide ramping capabilities.

b) *SNSP Issues:* Occurs when the System Non-Synchronous Penetration must be reduced to stay within limits.

c) *ROCOF/Inertia:* Used when the Rate of Change of Frequency (ROCOF) value for the loss of the largest single infeed is unacceptably high and wind must be dispatched down as a result or when the system inertia is too low (below 20,000MWs).

4) *Other Reductions:*

There are a number of reductions which also fall into this category, however have not been logged due to them being outside the TSO control. The ones which are listed are:

a) *Distribution Constraints:* Occurs when the Distribution System Operator or the Distribution Network Operator request a dispatch.

b) *Developer Outage:* Occurs when a wind farm must reduce output, mainly to carry out software upgrades.

c) *Developer Testing:* Occurs when testing is carried out by a wind farm developer.

3 2016 dispatch-down & wind figures

In 2016 a decrease in wind generation was observed which was mainly due to the reduced wind speeds throughout the year, with the average wind speed across Ireland dropping by 9.8%. The installed wind capacity had increased by 21.3% between 2015 and 2016, with the generation dropping by 6% meaning the wind capacity factor was cut from 33% to 27%. This observation helps give an idea on the problems with reliance on wind generation and the need for a very dynamic system.

When we consider the dispatch-down of wind many previous studies have focused mainly on SNSP problems and the necessary limits needed to meet renewable energy targets based on the predicted installed capacities [3]. However, Figure 1 shows the average hourly dispatch-down energy of wind for the winter months (January, February and December). It can be observed that the three many contributors are TSO Constraints, HighFreq/MinGen and SNSP, with the other categories contributing little of significance to the overall power loss, apart from "Other Reductions" which are unavoidable/ uncontrollable.

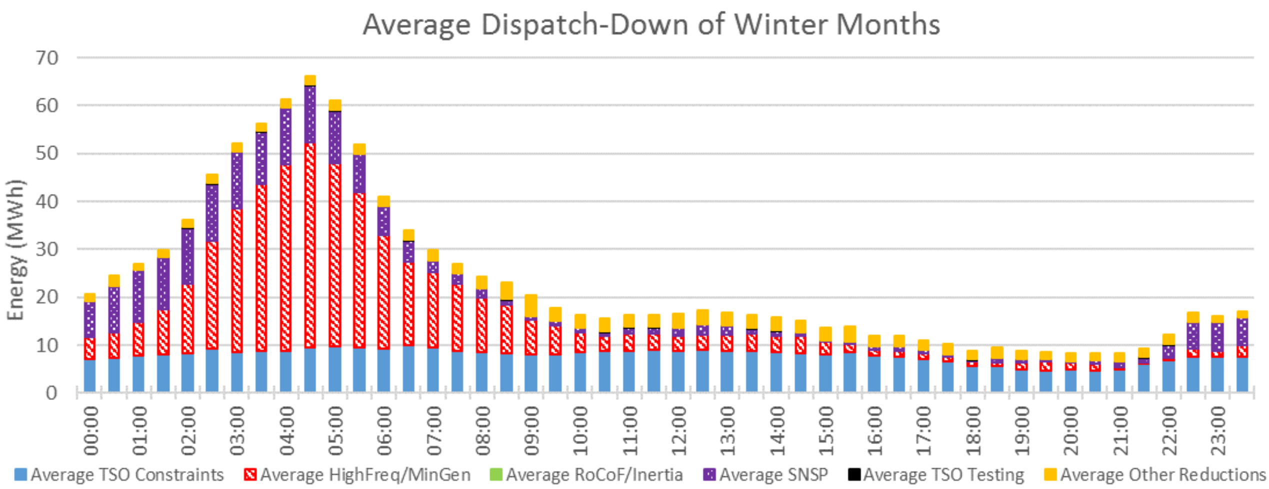

Fig. 1. Daily average dispatch-down during winter months.

The TSO constraints are very constant throughout the average day, with curtailment due to HighFreq/MinGen and SNSP spiking considerably during the slump in night time demand.

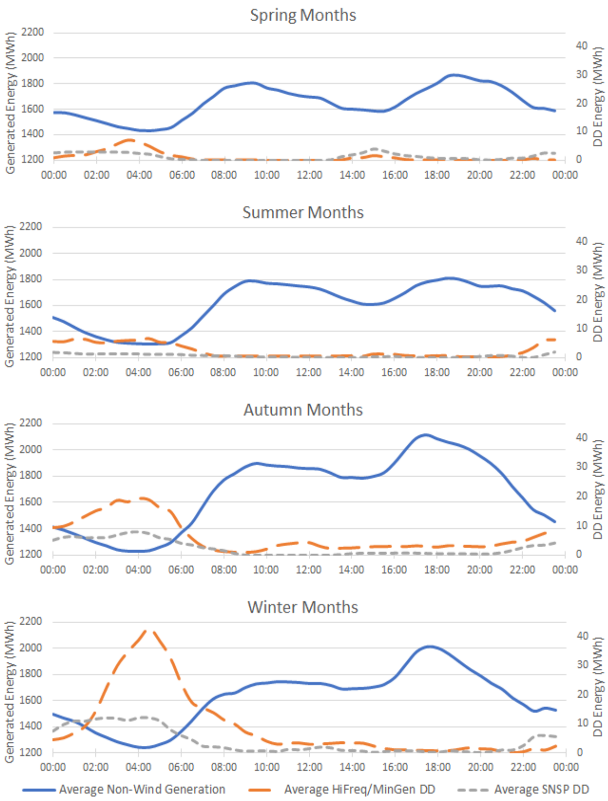

Fig. 2. Daily seasonal average of HighFreq/MinGen and SNSP against non-wind generation.

This trend is even more apparent when viewing Figure 2 which shows the relationship between the dispatch-down due to HighFreq/MinGen and SNSP against the generation of non-wind sources. In 2016 dispatch-down of wind was 2.9% (245.8 GWh), of this 33.8% (83 GWh) was due to HighFreq/MinGen and 14.4% (35.5 GWh) was due to SNSP. The fact that HighFreq/MinGen causes such a substantial amount of energy loss, shows that potentially it should be the focus of more research.

Table 1 presents the percentage breakdown of the wind dispatch-down for each season. The large percentage of TSO constraints in summer correlate with the large number of outages during this period [5]. This is mainly due to the amount of upgrading and uprating of the transmission system, as this is generally the season with the lowest wind generation and demand.

The most interesting point to be made from this table is again related to the curtailment due to the HighFreq/MinGen. From Figure 2, it can be observed that the non-wind generation has a very apparent correlation with HighFreq/MinGen. As the night time non-wind generation decreases for each season the related percentage of HighFreq/MinGen dispatch-down increases, with Autumn having both the lowest average non-wind generation point and the highest percentage of HighFreq/MinGen dispatch-down. Even though the data in this paper is from a year with lower average wind speeds, which may have skewed the impact of SNSP, there is still the premise to investigate the matter further as data from future years becomes available.

Table 1. Breakdown of seasonal dispatch-down.

	TSO Constraints	TSO Testing	HighFreq / MinGen	SNSP	RoCoF / Inertia	Other Reductions
Spring	52.8%	0.1%	16.3%	17.7%	0.0%	13.1%
Summer	72.7%	0.0%	18.8%	4.7%	0.0%	3.7%
Autumn	32.7%	0.0%	44.6%	16.6%	0.5%	5.5%
Winter	33.7%	0.3%	39.9%	17.0%	0.0%	9.1%

Table 2. Breakdown of yearly dispatch-down.

	TSO Constraints	TSO Testing	HighFreq / MinGen	SNSP	RoCoF / Inertia	Other Reductions
Spring	6.5%	0.0%	2.0%	2.2%	0.0%	1.6%
Summer	15.1%	0.0%	3.9%	1.0%	0.0%	0.8%
Autumn	8.3%	0.0%	11.4%	4.2%	0.1%	1.4%
Winter	14.0%	0.1%	16.5%	7.0%	0.0%	3.8%

The cause of HighFreq/MinGen dispatch-down is likely to be mainly due to facilitating the minimum level of conventional generation required, in order to provide dynamic stability, voltage control and system reserve [14]. The potential effects of providing reserve capabilities can be observed in Figure 2, as shown the curtailment of wind begins to increase at around the 22:00 mark for all seasons, approximately when the system demand begins to decrease below generation. However, during the winter months as the curtailment increases the non-wind generation actually increases as well. Source data also shows that around the same time interconnection on average begins to net export to GB and at 23:00 the NightSaver electrical tariff (used for electric storage heaters) comes online. With this observation and the consideration of EirGrid source data, the assumption is that conventional generators are being dispatched above their minimum base load at this time, in order to provide negative reserve (i.e. fossil generation being increase while wind generation is being curtailed) due to the potential volatility of relying on interconnection export load.

4 Benefits of controlled electric heaters on the all-Ireland grid

With the use of DSM capable electric heaters along with the incorporation of a communications network, the potential benefits for both grid and costumer are vast.

Table 2 shows the percentage breakdown of the dispatch-down for the whole year. This indicates that during the colder seasons more dispatch-down occurs, correlating with the demand of space heating. The use of electric storage heaters usually coincides with the use of an off-peak tariff. In the ROI the relevant off-peak tariff is called NightSaver (winter 23:00-08:00, summer 00:00-09:00) and in NI it is Economy 7 (winter 01:00-08:00, summer 02:00-09:00).

Off-peak tariffs are used to incentivise night time load in order to balance the demand profile. If electric storage heaters are used for DSM, their operating time will need to occur during the typical off-peak schedule as losing off-peak demand would likely create greater problems on the grid. Thankfully from Table 3 it can be observed that a huge portion of the dispatch-down occurs during these off-peak hours (NightSaver used).

Table 3. Breakdown of yearly dispatch-down during nightsaver tariff.

	TSO Constraints	TSO Testing	HighFreq / MinGen	SNSP	RoCoF / Inertia	Other Reductions
Spring	2.3%	0.0%	1.7%	1.1%	0.0%	0.5%
Summer	6.5%	0.0%	2.9%	0.7%	0.0%	0.3%
Autumn	3.0%	0.0%	7.5%	3.3%	0.0%	0.3%
Winter	5.7%	0.0%	13.2%	5.7%	0.0%	1.1%

From the DNV KEMA Energy & Sustainability report previously discussed, there are approximately 360,000 electric storage heaters on the ROI grid alone (this does not include the potential NI capacity). With this number of heaters there are huge potential benefits for using DSM with electric storage heaters for reserve capabilities, even when implemented with a basic communications network. If we considered that even just 10% of these heaters were to be DSM enabled/online at any one time, the grid impact in 2016 would have been significant. A new medium sized electric storage heater has an input of around 2.2 kW with a storage capacity of 15.6 kWh [15]. If the 10% of DSM enabled storage heaters were to be this capacity, in 2016, 91% of HighFreq/MinGen and SNSP curtailment during the winter NightSaver time period would have been potentially available (464.8 MWh of the 510.1 MWh). It is less than 100% due to the medium sized electric storage heaters only being able to provide a maximum 39.6 MWh of storage per half hour period. This is based on the assumption that providing a dispatchable load would be categorised as reserve, this would have eliminated the majority of SNSP curtailment during this period (154.8 MWh) and potentially reduce the HighFreq/MinGen considerably.

5 Communications & DSM

For the implementation of DSM incorporated electric storage heaters a low latency communication network would need to be setup. The heaters would then be aggregated together into larger loads "units" which would be of a sufficient size to be included in system scheduling for dispatch capabilities. With the implementation of this conceivable communications network the response of the storage heaters would be included in the primary operating reserve (POR) category (response time within 5 seconds). For this to work correctly, real-time information on the number of online units will be necessary as well as the available capacity, however this would need very little bandwidth in comparison to other types of data transmission. Emerging technologies in the 5G / IoT space are promising in this regard [16].

Even with a basic non-automated system, the electric storage heaters could still be used as reserve and be dispatch-down as an interruptible load similar to Turlough Hill pump storage. The install of new smarter storage heaters also brings the ability of self-contained system stability control with frequency response integrated. This however would need to have offset control in order to allow large amounts of capacity to respond in stages and prevent further large RoCoF changes.

The TSO has set the SNSP ceiling at 75% meaning their target for curtailment is 5% [17], as there will be times when potential wind generation exceeds 75% of demand and exports.

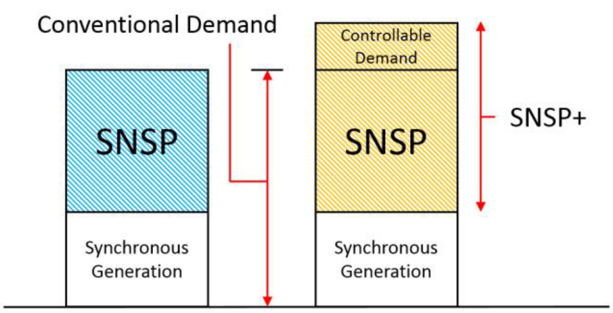

Fig. 3. Definition of "SNSP+" in the system.

Due to this 75% limit, DSM on the network would be necessary to allow for an increased amount of SNSP generation. Figure 3 helps with the understanding of how this would work describing the new generation type as SNSP+. As the controllable demand would also be essentially supplied entirely by SNSP, it can be argued to have zero carbon emission, helping to greatly reduce the system's CO_2 output.

6 Future work

This paper proposes the idea of using electric storage heaters as a means to provide system reserve capabilities using DSM. To give a full understanding for the potential benefits of this scheme future work is necessary:

- Evaluate the single electricity market operator's (SEMO) data to see the dispatch of generator units during the time of curtailment and clarify if they are supplying reserve capabilities.
- Model large scale DSM uptake to produce more realistic assumptions in terms of curtailment reduction and potential frequency response capabilities.
- Consider the potential of providing negative reserve, due to the scheduling of many units. (Having dispatchable load on the system but offline meaning it can be switched on if necessary).

7 Conclusion

The paper has considered the implementation of DSM as a means to provide system reserve capabilities. Household space heating in the form of electric storage heaters has been shown to be a good option for this application, as demand for off-peak electricity coincides precisely with a large portion of the two main sources of curtailment (HighFreq/MinGen and SNSP). The majority of this curtailment has been assumed to be due to the network having to facilitating the minimum level of conventional generation to satisfy reserve requirements. This point was furthered with Table 1 and Figure 2 showing that as night time non-wind generation decreased, the related percentage of HighFreq/MinGen dispatch-down increased.

This paper also considered the reserve category in which this DSM would fit, due to the communication schemes available. It is highly conceivable that it could be used as POR. Even with a slower less automated system it could be used in a similar way to pumped storage, being dispatched-down as an interruptible load.

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